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Boosting STEM Success Through Calculus 2 Workshops

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In this paper, we discuss the design, implementation, and assessment of an intervention measure, Calculus 2 Workshops, to improve students' performance in Calculus 2. The central role of Calculus 2 in Science, Technology, Engineering, and Mathematics (STEM) makes the course a gateway to success in STEM. Having implemented Calculus 2 Workshops at a mid-size University in the United States, we document key elements of our successful program and use descriptive statistics to analyze the data on passing rates. Our results show that this method of intervention significantly improved our students' passing rate, from 50% to over 70% in two semesters. Not only did the measure help our students' performance in Calculus 2, but it also helped participants to develop an appreciation for group work, cooperative learning, and community building that is based on shared academic and career interests. We provide suggestions for institutions who wish to utilize a similar measure to cure the nagging issue of lackluster performance at the formative stages of their college education.

Keywords: second semester calculus academic workshops, STEM success

Introduction

Mathematics has been an integral part of the foundation for growth and intellectual maturity in all areas of study leading to almost all careers in life. This accounts for why reading (comprehension) and mathematics are the two areas around which secondary school curricula are built worldwide. Since textbooks are written to be studied and understood, comprehension is necessary for appropriate literacy in all other areas of study. However, problem-solving, critical thinking, proportionality, and analytical acumen are all derived through mathematics almost exclusively. At the General Education level in college, the same themes are expanded to give the student a well-rounded liberal arts education. In the United States, areas of study in Education, Social Sciences, Arts, and the Humanities utilize a combination of College Algebra, Introductory Statistics, and Liberal Arts Mathematics while areas of Business extend this list to include Business Calculus. In contrast, for a successful study in Science, Technology, Engineering, and Mathematics (STEM), the Calculus Sequence constitutes the main General Education mathematics block. The major themes of differentiation, integration, and multi-variate calculus permeate STEM, although nonuniformly, and the extent is dependent on the types of applications encountered in the specific area. Thus, heightened success in STEM is dependent rather heavily on students' performance in the calculus courses.

For quite some time now, colleges, universities, and policy-making bodies have been grappling with students' performance in the calculus sequence because of its centrality in STEM. The decline in the number of students

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who complete studies in STEM areas is directly linked to poor performance in the calculus sequence. Institutions of higher learning in the United States continue to implement measures with the hope of raising the success levels in this sequence. Examples of such measures include: implementing project-based learning on a large scale in the calculus sequence (Fox et al., 2017); introducing web-based homework to replace the traditional mode of paper and pencil (LaRose, 2010); changing department policies to include instructional methods, grading policies, and passing conditions (Norton, High, & Bridges, 2017); promoting success in targeted courses in the calculus sequence (Bullock, Callahan, & Cullen, 2018); and identifying demographics in the society most affected by lackluster performance in the calculus sequence and attempting to understand underlying factors responsible for their fate (Anderson, 1990; Flores, 2007; Fullilove & Triesman, 1990; Triesman, 1993).

In this paper, we discuss a concrete strategy, *the Academic Workshops*, for boosting students' performance in the calculus courses. Based on our experience at the University of West Florida (UWF), that we began in the Fall Semester in 2010 and fine-tuned it to a science over the course of five-six years, we examine the design, implementation, and assessment of our strategy. Among the Calculus sequence, passing rates were worst (about 50%) in the second semester calculus course. Thus, we focused initially on this second semester course, Calculus 2. We note, however, that the core elements of this strategy have worked equally well with minimal adaptation in mathematics courses before and after Calculus 2, as well as in general education courses in other disciplines such as chemistry, biology, physics, computer science, and environmental sciences. It is well-known (Steen, 1988) that among the calculus courses that form the gateway to STEM, Calculus 2 is a baseline that approximates a "filter". It is a key prerequisite to other courses such as University Physics, Differential Equations, Calculus 3, and Engineering Mathematics, to mention a few. Moreover, most professional examinations in STEM disciplines such as pharmacy, actuarial sciences, and engineering always have a section dedicated to Calculus 2. Thus, that Calculus 2 has the worst passing rate of all STEM gateway courses in the United States (Steen, 1988) highlights its importance to success in STEM.

Several issues are responsible for the difficulties that students face in their study of the material in Calculus 2. Prominent among these are:

- Calculus 2 depends heavily on PreCalculus Algebra (functions and their graphs), Trigonometry (roughly 40% of problems involve trigonometric functions), and Calculus 1 (as a process, the theme of integration in Calculus 2 reverses the differentiation that is the central notion in Calculus 1). Deficiencies in any of these three courses can easily lead to monumental roadblocks in students' performance in Calculus 2.
- Many manipulations in Calculus 2 utilize the spectrum of a student's mathematics experience. For example, some students may not have used skills such as completing-the-square for years after learning it in high school. To their chagrin, that skill is required in Calculus 2 at pivotal points where nothing else will work.
- Most formulas in Calculus 2 are geometric models, not a plug-and-chug as with rules of differentiation in Calculus 1. To illustrate this point, the formula for obtaining the volume of a solid of revolution by means of cylindrical shells is

$$V = \int_a^b x f(x) dx,$$

where x is the distance from the shell to the axis of revolution, and $f(x)$ is the height of the shell. To successfully use this formula in each situation, the student must (a) know the formula, (b) determine that the geometry of the situation is appropriate to deploy the use of the formula, and most importantly, (c) learn how to calculate the two geometric quantities involved in the formula.

- In Calculus 2, hard and fast rules are not readily available. Within one method, distinct types of problems demand different choices. Thus, seemingly like things demand non-similar applications of a given formula to resolve. For example, while we must use the formula for integration by parts ($\int u dv = uv - \int v du$) for each of the two integrals.

$$\int x^2 e^{2x} dx \text{ and } \int x^2 \ln x dx,$$

we must choose $u = x^2$ in the first integral but we must not choose $u = x^2$ in the second. Before the point at which students are taking Calculus 2, connecting dots and using the deeper thinking necessary to make an informed decision on the application of a formula may not have been required or expected. It is to be learned in Calculus 2.

These and many other unique issues have been roadblocks for success in Calculus 2. For a group of students engaged in learning the Calculus 2 material, efficient remediation on a large scale may not be easily discerned because students within the group often need different types of remedial help. A commonly utilized remediation tool is tutoring (Steen, 1988). Its limitation hinges on the varying needs of different students within one class. When assessment studies are followed by curriculum shifts and/or mode of teaching and learning mathematics over a reasonably long period but with minimal gains from these strategies, it becomes reasonable if not necessary, to look elsewhere for strategies beyond the normal.

Academic Workshops

Academic Workshops are rooted in group-learning strategies that are seen to be successful among many student groups. Although the literature on its origins is not robust, in more recent times the idea has been popularized by Professor Uri Triesman (1992; 1993). In its purest form, the concept of Academic Workshops avoids the pitfall of other mitigating initiatives that isolate the group targeted for help, thereby stigmatizing the group inadvertently. In contrast, it utilizes shared interests in intellectual development and similar professional objectives, to forge cooperative learning that enhances community building. Two main variants or adaptations of the idea have been used with excellent results across several subject areas and in programs such as the Minority Engineering Program, MEP (Ohland & Zhang, 2013), and Emerging Scholars Program (Asera, 2001; Triesman, 1993), as well as the Wisconsin Emerging Scholars program (Bain, Burda, & Miller, 1997). By the mid-1990s, these programs became popular in many notable U. S. universities and colleges including California Polytechnic-Pomona, City College of New York, University of Texas-Austin, Wayne State University, Rutgers, University of Kentucky, Glendale Community College-California, FAMU-FSU College of Engineering, Tallahassee, and Seattle Central College, among others (Bain, Burda, & Miller, 1997; Bullock, Callahan, & Cullen, 2018; Ohland & Zhang, 2013; Triesman, 1993). The Academic Workshop has features that clearly distinguish it from a tutoring venture: students studying the same material are given selected problems to work in small groups under the supervision of a facilitator, preferably a student of more advanced standing. Shared learning in this setting leads to friendships and comradery between and among participants regardless of students' characteristics. The voluntary nature of group formation permits learners' interest to govern group membership.

At the University of West Florida (UWF), we typically offer four sections of Calculus 2 during each of the Fall and Spring semesters, and two sections in the summer term. We routinely assess students' performance in Calculus 2 using 10-12 common questions on a final examination. Our assessment helps us to identify areas of weakness and the respective Student Learning Outcomes of concern. Members of the faculty who teach the course then discuss and agree on ways to address those problem areas. Over the 10-year period (2000-2010), we stepped up individual and group tutoring to improve students' performance, yet our passing rate in Calculus 2 continued to hover at approximately 50% which was unacceptable. During the same period, we also went through iterations of curriculum shifts and various modes of homework/assignments (pencil and paper, online/web-based, and a hybrid of the two) with little or no gains in students' performance. We decided to adapt the *Academic Workshop* model beginning in Fall 2010.

Calculus 2 Workshops—Our Model Design

In preparation for implementing workshops in Calculus 2, we agreed to:

- Name a senior faculty member to coordinate all aspects of the Calculus 2 Workshops. This faculty member was dedicated and passionate about students' performance in Calculus 2.
- Produce a tentative schedule of workshop meetings times, staggered so that a workshop was held soon after the end of a class period. These were suitable times when students could engage outside the Calculus 2 class periods. Each Workshop was one hour long.
- Identify uniform departmental minimum homework for all sections of Calculus 2. Instructors had the freedom to assign additional problems for students in their classes.
- Formulate Workshop Problems (WPs) on each topic to be covered. WPs were typical problems for the topic at hand. All instructors were encouraged to contribute WPs. Problems were closely aligned with the minimum homework which in turn aligned with course objectives. Ideally, WPs were within the 70% medium-strength problems from which quizzes and tests were usually drawn. In fact, instructors contributed recent past quizzes and tests questions as WPs.
- Open each Workshop session to students from all sections of Calculus 2.
- Award some bonus incentive to students who participate. For instance, if five major topics constituted the material for an upcoming test, students who attended workshops on at least 80% of the topics were awarded three bonus points; those who attended workshops on 60% to 80% of the topics were awarded two bonus points added to their test score.

During each week:

- There were as many as six Calculus 2 workshops.
- Topics for the week were fixed and known to all Calculus 2 instructors. The faculty coordinator consulted each instructor periodically to ascertain that all sections were on the same topic during that week.
- Each workshop session touched on each of the topics for the week.
- Different but similar strength and type of problems from the same topic were given in each workshop session for the week. Thus, a student could attend as many workshops on the same set of topics as they wished.
- Instructors communicated with facilitators via the faculty coordinator and periodically commented on workshop-related issues in class.
- Calculus 2 instructors could drop-in on workshop sessions but were discouraged from staying there for the whole session. This boosted the students' morale without stifling the low-tone discussions that students were encouraged to have during the workshops.

Students discussed the WPs in small groups of three to five. They preferred round tables rather than the usual rows and columns in a classroom setting. They choose their group but could relocate as they needed. The facilitator provided limited help by way of hints to a group that needed assistance, but the facilitator did NOT remain with a group to tutor. When a group finished a problem, another problem was given. The facilitator took attendance at the beginning of each session.

Why It Works

Within one class, students do understand a given lecture to varying degrees. Moreover, due to instructors' various teaching styles and the nature of their explanation of a given concept, students from different sections of Calculus 2 may also have varying insights into a given topic. The Calculus 2 Workshops homogenized students' understanding of the material within and across all sections of the course. A given WP was not one person's headache; it was a group issue. Good students simply got better with the workshops; weaker students gained basic strength that they lacked to become more confident. The workshops also gave participants a hands-on head start on homework. The confidence that they gained from discussing a few typical problems provided the impetus to tackle homework problems solo. In fact, such participants grew more eager to ask questions about the homework because they attempted it. Since WPs were mostly past examinations questions, participants consciously or unconsciously got familiar with the types of questions that they would be given on their future quizzes and tests. Moreover, the workshops introduced students to group learning and community building, important traits that are not taught in any class. Ties that they developed in the workshops were based on common intellectual objectives that, if nurtured, morphed into professional and career goals. For many students, such ties lasted throughout their academic career at UWF. It was routine to see such student groups registering for the same courses beyond Calculus 2 and studying together. Very importantly, workshop participants did not feel singled out or isolated; they became keenly aware of how others in their class were doing and strategies that people experiencing hiccups were using to cope and get ahead. Finally, the workshop facilitators played a pivotal role in the success of the students and the whole enterprise. They gained the trust of the students so that their referral to resources on campus were taken as gospel. It was the reason for carefully selecting and thoroughly training the facilitators who would help the students to reap the maximum benefits from the workshops.

Facilitator Guidelines

In each workshop session, the facilitator:

(1) Prepared for the session and solved each of the problems to be used.

(2) Took students' attendance at the beginning of the session.

(3) Put one problem (or a few problems) up on the board or screen at a time.

(4) Encouraged the students to work in small groups within which they were encouraged to discuss in low tones. This encouragement to "talk" was reason for not allowing instructors to facilitate the workshops.

(5) Walked around and ensured that each group was making progress on the given problem(s).

(6) Gave hints for no more than one-two minutes if a group appeared to be stuck or clueless.

(7) Either solved the problem on the board (to teach them how) or asked any group that had solved the problem correctly to put up their solution on the board if several groups had issues with a given problem.

(8) Ensured that no group was idle throughout a workshop session. The facilitator put up a new problem when one group had finished solving the given problem.

(9) Resolved the easier problems completely, answering questions about such solutions. However, it was not necessary to completely solve each problem. Groups could complete some of the problems after the session.

(10) Gave three-six problems during each hour-long session depending on the topic. In fact, the facilitator permitted each group of students to dictate the pace at which they worked.

Aside from weekly reports that facilitators gave to the faculty coordinator, they conferred with the coordinator if any issues arose. In many instances, we used one facilitator for each workshop session. Two facilitators were used if a particular period attracted more than five groups of students. Similarly, new facilitators were paired with seasoned ones who would rotate off those duties in a future semester. The facilitator, with the help of the faculty coordinator, classified the problems by type and produced several sheets of problems of similar strength and types for the week.

Sample Workshop Problems

The following is a sample set of problems for a workshop on the topic: Integration by Parts.

Calculus 2 Workshop 7A

Integration by Parts

Formula: $\int udv = uv - \int vdu$

1. $\int xe^{-2x}dx$; choose $u = x$.
2. $\int x^2 \cos 2xdx$
3. $\int x^2 \sin 3xdx$
4. $\int x^2 \ln xdx$
5. $\int \sin^{-1} xdx$
6. $\int x^2 \sin^{-1} xdx$
7. $\int_0^1 \ln(2+x)dx$
8. $\int e^x \cos 3xdx$
9. $\int e^{2x} \sin(3x)dx$
10. $\int \sin(\ln x)dx$

Figure 1. A typical workshop sheet.

Note that problems 1-3 are of Type 1 (*u* must be the polynomial); problems 4-7 are of a second type (*u* must not be the polynomial); and problems 8-10 belong to Type 3 (the revolving integral where the choice of *u* is immaterial). Facilitators would use a given sheet to formulate similar problems to be used in other sessions when Integration by Parts is the topic of the week.

Assessment

To assess the effect of the workshops, we used descriptive statistics to record test and course results for each class. Since most STEM majors require a grade of at least C in Calculus 2, we considered grades of A, B, and C as passing grades. D, F, and W (withdrawal) grades were failing grades. Table 1 below is a typical example of students' performance on Test 2 (Integration) in one class during the summer term of 2018. We assessed students' group performance in four categories: the whole class (Overall), workshop participants with bonus points included (WS), workshop participants with bonus points excluded (WS-NB), and nonparticipants of the workshops (NWS). As Table 1 shows, the passing rate for the whole class was 73.33%, approximately 20 percentage points higher than the passing rate on Test 2 in the course before we implemented the workshops. The passing rate for workshop participants was 93.55% which was significantly higher than that of the whole class, and a whopping 65% higher than the rate for nonparticipants. When we excluded the token workshop bonus points from our tabulation, the passing rate held steady at 93.55% while one grade dropped from an A to a B and 2 B-grades changed to Cs. The effect of the workshops was transparently evident.

Table 1

Typical Students' Performance on Test 2

Sum 2018 Test 2	A	B	C	D	F	Passing rate
Overall	12	10	11	10	2	73.33%
WS	11	9	9	2	0	93.55%
WS-NB	10	8	11	2	0	93.55%
NWS	1	1	2	8	2	28.57%

At the end of each semester, as with hourly tests, we tabulated course grades for the whole class, then for workshop participants only, and for non-workshop participants. Table 2 below shows the course grades for a typical class in the summer term in 2018. As the table shows, the passing rate for workshop participants was 93.1% which was very high compared to the 37.5% passing rate for nonparticipants. In fact, the overall class performance of 71.74% passing rate, which is lower than the 93.1% rate for workshop participants, still 20% points higher than the passing rates in Calculus 2 before we implemented the workshops. The group grade point averages (GPA) were 2.44, 2.93, and 1.56 for the whole class, workshop participants, and nonparticipants, respectively. Thus, the workshop participants averaged close to a B grade (B- to be precise) while the whole class averaged a C+ grade and nonparticipants of workshops lagged far behind with a D+ grade.

Table 2

Semester Grades and Passing Rates for a Typical Class

Sum 2018 Semester	A	B	C	D	F	W	Passing rate	Group GPA
Overall	12	10	11	10	2	4	71.74%	2.44
WS	10	9	8	2	0	0	93.1%	2.93
WS-NB	9	9	9	2	0	0	93.1%	2.86
NWS	2	1	3	8	2	4	37.5%	1.56

We note also, that four of the nonparticipants of workshops dropped the course (with the W-grade) but none of the workshop participants dropped. As before, we removed all bonus points awarded to workshop participants and re-computed semester grades for workshop participants. As can be seen from Table 2 (WS and WS-NB), there were two grade changes: an A grade turned into a B and one B grade changed to a C. The passing rate of 93.1% remained while the group GPA dropped from 2.93 to 2.86. This new group GPA was still appreciably higher than the overall group GPA of 2.44 and the abysmal 1.56 GPA of nonparticipants. Two main conclusions can be deduced from this comparison: (a) while the workshops helped to raise the group performance of workshop participants and the whole class, most students engaged in the workshops no longer needed the bonus points in order to make the grades that they made and, very importantly, (b) the bonus points awarded to workshop participants did not create a grade inflation for the class. We also mention that the surveys we gave to the students by mid-semester showed that initially, some high-performing students elected to participate in the workshops to accrue a few bonus points to ensure a good grade. However, their continued participation beyond two of three hourly tests was a result of their positive experience in the workshops.

Finally, Table 3 below shows passing rates in one professor's Calculus 2 classes over a twelve-month period of three semesters. We perceive that the students' performance during the Fall semester, in comparison to other semesters, may be because many students who took Advanced Placement (AP) classes in high school were introduced to calculus. Such students were placed in Calculus 2 when, in reality, some of them were not ready for the course.

Table 3

Passing Rates in a Professor's Calculus 2 Classes

Term	A	B	C	DF	W	Rate with W-grade	Rate without W-grade
Summer 2019	12	10	11	9	4	71.74%	78.57%
Fall 2018	5	9	9	7	7	62.16%	76.67%
Spring 2019	9	11	10	10	5	66.67%	75%

While these rates may not be great, the worst of them is approximately 12 percentage points better than rates that we experienced prior to engaging the Calculus 2 Workshops. In each of these classes, students who participated in Calculus 2 workshops performed as well as those in Table 2.

Summary

Students who participated in Academic Workshops in Calculus 2 performed significantly better than those who did not. The workshops raised the level of students' performance for the whole class. Participants adopted the concept of study-group into their academic culture. Workshop bonus points were enticing to some students who may otherwise have ignored the workshops. If given appropriately, they did not lead to grade inflation. The gains from workshop participation lasted far beyond Calculus 2.

Suggestions

For departments wishing to engage in Academic Workshops in a course, we have a few suggestions that may be helpful in such a quest. Name a respected senior faculty member to coordinate the workshop operation on behalf of the department. The authority that the coordinator commands, while collegial, is the glue that holds the operation together. Create uniformity in the homework assignments for all sections of the course and give a common final examination. Have a tentative schedule for instructors to discuss topics so they move through the course material at about the same pace. It is critical to give workshops on the same topics within a given week. Select and train student facilitators well. Assess students' performance often, to identify areas of concern. Perform curriculum shifts and utilize WPs to address those areas of concern. Make tangible efforts to raise the performance levels of your general education courses. These can be fertile grounds for recruitment to your major.

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